Spintronics using local angular momentum of surface acoustic wave

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Spin-vorticity coupling (SVC), which is one of the general relativistic effects in rotating body, enables us to convert mechanical angular momentum with magnetization, i.e. spin and/or orbital angular momentum of electrons. Since a novel type of spin current (SC) generation via SVC in a surface acoustic wave (SAW) was theoretically predicted by Matsuo et al.[1)], experimental studies on the SVC had been reported by several groups. Recently, we have succeeded to demonstrate a spinwave resonance (SWR) excitation via alternating SC generated in a NiFe(20 nm)/Cu(200 nm) bilayer deposited on piezoelectric $LiNbO_3$ substrate when the Rayleigh-type SAW is applied[2)]. However, there are still some open questions. First, there is no clear evidence that a gradient of SAW vorticity needed for SC generation exists in 200-nm-thick Cu film. Second, to understand the SVC quantitatively, we must evaluate the alternating SC in Cu as a function of amplitude of lattice deformation. Third, the theory expects two different sources for spin accumulation. One is the time derivative of local angular momentum Ω, and the another is Ω itself. We must examine which is dominant contributor for the SC generation. Moreover, there is a renormalization factor in the analytical expression of SC which is hard to be determined theoretically. It is significant to quantify this factor because the magnitude determines the conversion efficiency between the local angular momentum of the SAW and spin angular momentum. To improve the understanding in the microscopic mechanism of the angular momentum conversion between microscopic electron spin and macroscopic angular momentum in the SAW, we need quantitative information on the magnitude and spatial distribution of the SAW in the bilayer system.

In this symposium, we will show our recent experimental studies on (i) highly nonreciprocal SWR excited using magnetoelastic coupling in Ni/Si bilayer[3)], (ii) reciprocal SWR excited using gyromagnetic coupling in NiFe single layer[4)], and (iii) electrical measurement of alternating SC in NiFe/Cu bilayer[5)]. The nonreciprocity of the SWR owing to a shear strain component was strongly enhanced by embedding the Ni far from the surface. From the variation of the nonreciprocity on the thickness of Si covered on the Ni, we can estimate the depth profile of the relative amplitude of the shear strain component with respect to the longitudinal strain component that gives the spatial distribution of the SAW. Moreover, a picometer order SAW amplitude averaged over the NiFe film was experimentally evaluated from the amplitude of SWR excited via gyromagnetic effect whose amplitude was simply given by the vorticity of SAW. Finally, from the comparison between the amplitude of the alternating SC in NiFe/Cu bilayer and the SAW amplitude evaluated, we found that the conversion efficiency of the angular momentum from the SAW to the electron spin was much larger than in the spin current generation using a vorticity of liquid metal[6)]. Theoretically, the conversion efficiency of the angular momentum from the lattice into electron spins becomes larger when the difference of the energy scales is smaller between lattice motion and spins. Consequently, the renormalization factor of the elastic system is much larger than that of the liquid-metal flow because the elastic motion of our setup is in the gigahertz range whereas the vorticity of the liquid-metal flow is in the kilohertz range.

Reference

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